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Study of Curvilinear Structural Features in the Parry Sound Area, Grenville Province, using Landsat Thematic Mapper-Images

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Study of Curvilinear Structural Features in the Parry Sound Area, Grenville Province, using Landsat Thematic Mapper-Images

by

M.L. Tremblay

1989

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V.G. Milne

V.G. Milne, Director
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Foreword

New insight into the structural framework of the Grenville Structural Province of the Canadian Shield in Ontario led to a subdivision of the gneissic terrains of the Parry Sound and Muskoka areas into several domains and subdomains which are juxtapositioned against each other along distinct boundary zones.

In a pilot project the author of this report tried to recognize these boundaries on Landsat satellite images and found that this is impossible based on lineament analysis alone. Lineament density and characteristic textures on satellite images, however, appear to correspond with local aeromagnetic patterns, and the author suggests that more refined lineament density maps may very well be used as good reconnaissance mapping tools.

V.G.Milne
Director
Ontario Geological Survey

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ABSTRACT

Curvilinear structural features of the Parry Sound area were analyzed at 1:100 000 scale. The Parry Sound Domain was found to be clearly visible on TM-images. The boundaries of the various domains were classified into three categories: 1-lineament belts, typical of the Parry Sound Shear Zone, 2- zones of truncations of lineaments, more common in the southern part of the area of investigation, and 3- gradual, which characterizes the eastern boundary of the Parry Sound Domain. A quantitative analysis of the lineaments were performed in the northern portion of the map. Lineament density was evaluated using the function D=(L)(N)/S, where L= cumulative lineament length, N= number of lineaments, and S= average lineament spacing. A contoured lineament density map was generated. Moderately good correlation with geological data and aeromagnetic data suggests that a more refined density map could assist geological mapping.

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STUDY OF CURVILINEAR, STRUCTURAL FEATURES IN THE PARRY SOUND AREA, GRENVILLE PROVINCE, USING LANDSAT THEMATIC MAPPER-IMAGES

by

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INTRODUCTION

The Parry Sound Domain forms part of the Central Gneiss Belt in the Grenville Province. It is located to the east of the Town of Parry Sound on Georgian Bay. Detailed mapping of the Parry Sound area was undertaken in 1986 to 1988 by the Ontario Geological Survey (Bright 1986, McRoberts and Tremblay 1987, McRoberts, Macfie and Hammar 1988) in order to improve the geological database for this domain of predominantly mafic to intermediate rocks.

The intent of this study was to analyze the curvilinear, structural bedrock features visible on remote sensing images and determine if the domain boundaries of the Parry Sound Domain (Davidson 1984, Davidson and Grant 1986) could be identified from the lineament distribution. This could help in the selection of future mapping sites. A secondary goal of the study was to develop a quantitative technique enabling the objective analysis of curvilinear, structural features, and to compare the results with more subjective visual analysis. This project involved the collaboration of Dr. V. Singhroy and F. Kenny from the Ontario Center for Remote Sensing, who provided technical equipment and support.

GENERAL GEOLOGY

The rocks of the Parry Sound Domain are Middle Proterozoic in age. They are interpreted to overlie the Britt and the Kiosk Domains to the west and east respectively (Figure 1) and the Rosseau Subdomain to the southeast (Davidson 1984). The Parry Sound Domain is in turn overlain by the Moon River and the Seguin Subdomains to the southeast. According to this interpretation, zones of intensely deformed rocks, such as the Parry Sound Shear Zone, form the boundaries between the various domains and subdomains. Granulite facies metamorphic grade typical of the rocks of the interior Parry Sound Domain is locally retrogressed to upper and mid-amphibolite facies, particularly within the shear zones and along the boundaries of the Parry Sound Domain. Brittle faults associated with the Ottawa-Bonnechere Graben (Kay 1942, Kumarapeli 1976) trend east to northeast with little displacement observed along them (Culshaw et al. 1988).

PREVIOUS WORK

Harris et al. (in press) investigated the curvilinear features of the Grenville Province of both Quebec and Ontario, at a scale of 1:250 000. They demonstrated that the curvilinear features were clearly visible on Landsat and Seasat images. They also found that, when analyzed visually, the lineaments could locally be correlated with known geological features such as tectonic domain boundaries, shear zones, and folds.

Their interpreted tectonic domain boundaries for the Parry Sound area (Figure 2) differ slightly from Davidson's (1984) framework. The Seguin Subdomain does not appear to have well defined boundaries, although they still place the Subdomain limits close to Davidson's. The northern boundary of the Parry Sound Domain is positioned further to the south, and do not identify the Amhic Subdomain. However, they place a small domain unrecognized by Davidson (1986) north of the Seguin Subdomain.

Visual interpretation may yield equivocal results, and lineament literature abounds in warnings against the subjective nature of lineament maps (Burns and Brown 1978, Parsons and Yearly 1986). This has stimulated research to measure the reliability and reproducibility of such maps (Burns and Brown 1978, Huntington and Raiche 1978, Koopmans 1986, Parsons and Yearly 1986). From this work, it is obvious that a high degree of variability may exist between different lineament maps of the same region, depending on technical factors such as the time of scene acquisition, bands used and resolution, and human factors such as interpretation criteria, experience and fatigue of the interpreter.

In order to perform a more objective analysis of lineament maps, it is becoming common to reduce the importance given to one given lineament, and instead emphasize lineament families. Lineament density is an increasingly used parameter in map

analysis (McGuire and Gallagher 1976, Sawatzky and Raines 1978, Abel-Rahman et al. 1978, Pitz and Thiessen 1986), although reservations have been recently expressed by Parsons and Yearly (1986). The author agrees that absolute density is an unreliable parameter, but thinks that relative density remains to be tested in geological applications.

In the literature, studies of straight lineaments are favored over curvilinear features, probably due to the interest of the mineral industry combined with the relative geometric simplicity. As a result, the quantitative study of curvilinear features is scarcely found in the literature (Peterson 1974). The methods used in these quantitative studies were not very successful. The method used in this study was first described by Tremblay (1988).

METHODOLOGY

Cloud free Landsat-5 TM-images of bands 4, 5 and 7 (Figure 3), acquired on October 25, 1986 were projected and enlarged to a scale of 1:100 000 over a mylar sheet using a Procom-2 projector to cover the Parry Sound Domain . This study is based on the assumption that curvilinear features reflect the trend of the foliation, which is supported by Harris et al.(in press), and by detailed mapping from McRoberts and Tremblay (1988). Concordant linear and curvilinear features subparallel to each other through to represent unit contacts, layering, foliation, ductile shear

zones were traced, while non-concordant straight features representing brittle structures were not traced. The curvilinear features in places are not concordant and may intersect one another. Some of the intersecting features possibly represent glacial features. However, McRoberts and Tremblay (1987) and Culshaw et al.(1988) showed that two phases of migmatization occurred in some parts of the Grenville Province, thereby generating two gneissic foliations. They may in places form intersecting curvilinear features visible on satellite images. Non-concordant curvilinear features therefore were traced so as to represent the two phases of ductile deformation.

It was found that previous field knowledge of some part of the map area influenced lineament recognition in a significant way. The discrimination between straight lineaments representing brittle features and curvilinear features was difficult in zones where no detailed bedrock geology map was available. In such cases, when there were doubts as to the nature of the lineament, it was eliminated from the map. This explains why more lineaments are shown in the better known northern part of the Parry Sound Domain (Figure 4, pocket), and the density in other areas may not reflect the true situation.

In the quantitative analysis, three parameters were used to evaluated the lineament density: "L"-cumulative lineament length, "N"-number of lineaments, and "S"-average spacing of lineaments.

Because the objective of the study was to determine the position of tectonic domain boundaries, it was desirable to find a technique that could help identify shear zones. From examination of Ramsay's diagrams (1980), it appears that the morphology of a shear zone is typified by more closely spaced foliation planes within the shear zone relative to the unsheared rocks. The lineament density therefore would be expected to be higher in a shear zone. In an attempt to enhance lineament density, the three parameters L, N, and S were used to determine a density factor, D:

$$D = (L)(N)/S$$

The variables L, N, and S can all be used independently to estimate density. The advantage of using the three parameters lies in the increased sensitivity to patterns that one variable alone would not identify (Figure 5). However, it is not possible to positively identify shear zones using this relation, as thin rock units may have lineament density highs unrelated to shearing.

L, N and S were measured for hexagonal cells 2 centimetres in diameter, measured from the corners (Figure 6), over an objective rhombic grid with a 1 centimetre spacing covering the northern portion of the curvilinear lineament map. "N" and "S" were measured across a line perpendicular to the trend of the lineaments within the hexagon and passing through the center of the cell. Results were then contoured. Lakes were treated as map boundaries and contours were stopped at their margins.

Hexagonal cells were chosen over other possible cell shapes because they optimize the area-radius ratio, and can cover an area completely (Sijmons 1978). The grid spacing, which is half the cell diameter, provides a greater degree of exactness (Sijmons 1978) than a spacing equal to the diameter of the cell. Sijmons (1978) suggests that a smaller cell size along with a smaller grid spacing (i.e. 1/4 the cell diameter) should be used. As all measurements were done by hand, with a mapping wheel and a ruler, to follow Sijmons' parameters would have resulted in increasing the error on the measurements and increasing the time required to perform the analysis by a factor of 16.

The analysis was first attempted at a scale of 1:50 000. This scale proved to be impractical, as the background noise due to areas of swamps, overburden, lakes, settlements and crops overshadowed the lineaments attributable to foliations. The results presented here deal only with 1:100 000 scale analysis.

RESULTS

Curvilinear Lineament Map

The identification of domain boundaries on the curvilinear lineament map was carried on using the same criteria used by

Harris et al. (in press): namely, the presence of truncation relationships and continuous belts of lineaments juxtaposed to zones of contrasting lineament distribution. An effort was made to typify the boundaries as simple truncation relationships, or lineament belts defined by a band composed of several concordant lineaments bounded on each side by zones of contrasting lineament distribution.

The Parry Sound Shear Zone appears to be the only boundary in the area of investigation defined by a truly continuous belt of lineaments (Figure 4 and 7, pocket). The width of the zone varies, but lineaments within it are highly continuous. The zone undulates gently which suggests that it is folded. The northern segment of the zone is narrower and gradually becomes only vaguely defined near the eastern margin of the domain. The northern-most arc-like boundary of the Parry Sound Domain boundary drawn in Davidson's map (Figure 1) does not appear to be part of the Parry Sound Domain in the lineament map. Instead, the lineaments delineating the arc-like structure appear to be truncated by the Parry Sound Shear Zone.

The eastern boundary of the Parry Sound Domain is not defined by either truncation relationships or lineament belts. Rather, it is represented by a gradual change in lineament density and orientation. This zone is one of a greater accumulation of Quaternary sediments (Mollard 1981a, b, c, d) and, although, the recognition of lineaments is difficult, the

recognized lineament distribution does not suggest the presence of a high strain zone.

An exception to this along the eastern boundary is the area corresponding to the Ahmic Subdomain. Here, a westerly closing fold pattern is clearly visible from the lineament distribution. This Subdomain boundary appears as a belt of lineaments truncating Parry Sound Domain structures to the west. As was the case for the eastern boundary of the Parry Sound Domain, it was not possible to define the eastern extent of the Ahmic subdomain.

The southern limit of the Parry Sound Domain is complex due to the juxtaposition of three tectonic subdomains. The southwestern margin is truncated by lineaments delineating a large northwest-trending fold, corresponding to the perimeter of the Moon River Domain. Truncation of the Parry Sound structures is sharp, although not defined by a belt of lineaments. Instead, the structure of the Moon River Subdomain is dominated by concordant continuous lineaments, with some internal variations suggesting earlier deformation. The boundary is concordant to the internal lineament pattern of the Moon River Subdomain, and a zone of higher strain at the margin cannot be identified from the Landsat TM-imagery. The northerly oriented structures of the Go Home Subdomain are also clearly truncated by the Moon River Subdomain.

Much like the eastern boundary of the Parry Sound Domain, the boundary with the Rosseau Subdomain is not defined by a lineament belt or truncation relationships, but is rather characterized by a gradual change in lineament patterns. The Rosseau's interval structures are folded about northeasterly axes and refolded about northwesterly axes. This interference results in circular map patterns. The limbs of the earlier northeast-trending fold set appears to truncate locally short lineaments, which suggests that the limbs were the site of shearing. Those limbs and the boundary between the Parry Sound Domain and the Rosseau Subdomain share the same orientation. The position of the boundary can be inferred from a very narrow zone of discontinuous lineaments. The absence of recognized lineaments adjacent to that zone does not permit the recognition of truncation relationships. Instead, Parry Sound Domain lineaments nearest to the boundary appear to share similar orientation. This boundary is thus classified as gradational.

Davidson et al. (1982) identified a tectonite zone separating the Parry Sound Domain from the Rosseau Subdomain, with "...marked truncation of the Parry Sound lithology, structure and metamorphism" (p.182). This is not recognized on TM-curvilinear lineament map, and may be explained by the relative lineament scarcity in the boundary zone.

The western contact of the Rosseau with the Moon River Subdomain is delineated by a belt of lineaments. The eastern

contact with the Seguin Subdomain is defined by truncation relations of the Rosseau's structures.

The northern extent of the Seguin Subdomain is poorly defined. The western limit adjacent to the Rosseau Subdomain appears to branch within the Parry Sound Domain, not curving into the Seguin northern boundary. Instead, the latter is offset to the south and is characterized by a wide zone of less continuous but sub-parallel lineaments. This subdomain is thus similar to the Parry Sound Domain, with a well defined western margin and a more diffuse northern limit. This suggests movement was concentrated along the western portion of the domains.

Internal Structures

The northern part of the Parry Sound Domain is characterized by medium length, northeast-trending lineaments, and short, more easterly trending lineaments.

Toward the south, it becomes increasingly difficult to identify concordant lineaments characterizing foliation. However, it is possible to delineate round and complex fold structures, two to four kilometres in amplitude, east of the Whitestone anorthosite. At least two fold generations are present. In the Moon River and Seguin Subdomain and the Britt Domain, similar patterns were recognized. In the latter, they are distributed in northeast-trending bands 10-15 kilometres in

width, bounded by lineament belts. These may represent structures pre-dating shearing along the lineament belts.

One can predict that in the field, the rocks within these zones would contain structures of different generations, rather than the more intensely deformed and transposed rocks contained in the lineament belts. It is usually in those zones that two sets of lineaments are found to intersect. One set can commonly be attributed to the fold pattern while the other locally appears axial planar to it. The trend of the latter set is commonly concordant to the trend of the lineaments outside the zone of intersecting lineaments.

Density map

The correlation between the lineament map (Figure 4) and the contoured density map (Figure 8) is relatively poor. In the density map, areas of high lineament density may locally parallel the trend of the foliation but they are more commonly oriented at an angle apparently unrelated to the structure. Although these areas are representative of high lineament density on the map, they cannot be readily used for structural interpretation. The zones of intersecting lineaments are in part responsible for intra-domain high density zones. It is suggested that some of these zones reflect structurally complex, although not necessarily sheared rocks.

When compared to the geological data (Figure 9), the density map shows a good correlation with the eastern boundary of the Parry Sound Domain as shown by Davidson (1984). However, since this is a gradational margin with respect to the lineament map, its positioning depends upon the lineament contour interval and thus its exact location remains arbitrary. In this zone, very low and high lineament densities are juxtaposed. The northern boundary of the Parry Sound Domain is well delineated in the east but absent in the west. The western boundary is marked by zones of intermittent high lineament density. At the northern and the western boundaries, the orientations of the high density zones parallel the trend of the lineaments. However, the presence of other high density zones, apparently randomly distributed throughout the Britt Domain, makes the identification of the domain boundary difficult in the absence of geological data.

A major northeast-trending shear zone within the Britt Domain recognized by Davidson and Grant (1986) is well delineated by the 100-contour (Figure 8)as a broad zone containing some high lineament density areas. This suggests that intra-domain shear zones could potentially be identified with density maps.

Correlation between the density map and aeromagnetic data (GSC, 1965a-d) yields more interesting results (Figure 10 and 11). Correlation between lineament density and aeromagnetic signature commonly corresponds in location and extent. Locally, high density zones correspond to aeromagnetic highs or lows.

This is best shown at the northern and eastern boundary of the Parry Sound Domain, where complicated patterns are present on both maps, almost in the same location.

DISCUSSION AND CONCLUSION

The extent of the Parry Sound Domain is defined by several boundary types, the western margin or the Parry Sound being the only one to distinctly suggesting a ductile shear zone boundary Shear Zone. The boundaries with the Seguin and the Moon River Subdomains are truncation relationships, and no zone of localized shearing can be identified. The eastern boundary with the Kiosk Domain and southern boundary with the Rosseau Subdomain are marked by a gradual change in lineament pattern and distribution, and do not suggest the presence of intensely sheared rocks.

The types of geological features associated with the various boundary types remain to be tested in the field. Macfie's analysis (1988) suggests that, in contrast with the Parry Sound Shear Zone, the boundary between the Parry Sound Domain and the Seguin Subdomain is not a clearly defined tectonic zone as shown by Davidson (1968), but he does not exclude the possibility of a more easterly located boundary.

It is impossible to evaluate Davidson's (1986) tectonic framework based on lineament analysis alone. However, the different domain boundary types suggested in the lineament

distribution may reflect various degrees of shearing and/or recrystallization typical of unique boundary regimes. Shear zones with predominantly extensional, compressional or strike slip components are all common in mountain belts and could show characteristic morphology. Such variations should equally be expected in Proterozoic terranes.

The density map correlates poorly with the lineament map, but shows interesting agreement with geological data as the domain boundary can be delineated. This suggests that a lineament study as described here could assist geological mapping, much as do aeromagnetic maps. Because it only retains the basic lineament information, ideally, the technique used in the present investigation could provide uniform and consistent data, independent of the investigator.

The correspondence with local aeromagnetic patterns is a positive result. One can speculate that aeromagnetic signatures depend on rock types, which in turn will display characteristic textures in a Landsat image. One of the factors influencing the textural variation is the lineament distribution. This may explain the correlation. Nevertheless, even this limited association suggests potential applications for more refined density maps as reconnaissance mapping tools.

Several factors handicap the quantitative analysis. The distribution of high density zones in the density map appears

greatly affected by the presence of swamps, lakes, rivers, overburden, and cultivated areas. These usually correspond to zones of low lineament densities, and offset the pattern attributable to geological factors. One way to compensate for this problem is to interpolate data in the low density zones (Frank Kenny, Assistant, Ontario Center for Remote Sensing, 1988, pers. comm.), or to treat swamps, lakes, etc. as map borders, and not generate data for these zones. In this map, these zones were found to be too numerous to apply either of these two solutions, as the map would have comprised 50% interpolated data with the first solution, or 50% of holes with the second one.

The zones of intersecting lineaments have been found to make the recognition of shear zones difficult, as they are also expressed as high density zones. It is suggested that these zones be treated differently in the measurement procedure (i.e. include an intersection factor) in order to enhance concordant lineament zones.

Another major drawback to the technique is the time necessary for the analysis. As noted earlier, a smaller cell size and a smaller grid would yield more exact results. However, this can hardly be done without the help of an automated image analysis system capable of performing these particular tasks. The existence of such a system is unknown to the author. Such analysis could reveal the true potential of the method.

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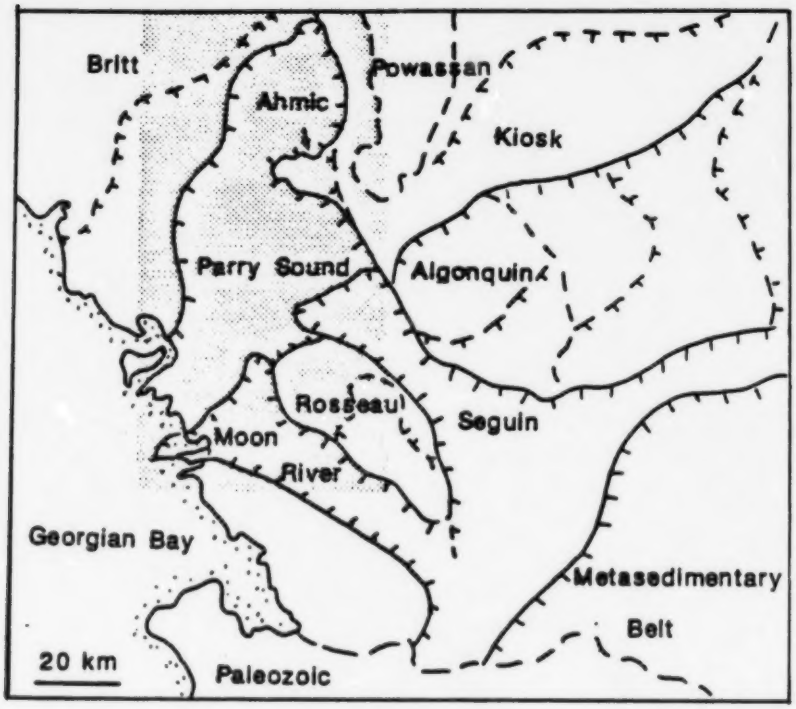


Figure 1: Tectonic Domains of the Parry Sound Area, redrawn after Davidson (1986). The Algonquin Domain is separated into several subdomains and the Muskoka Domain comprises the Seguin, the Rosseau and The Moon River Subdomains. The rectangle indicates the extent of the study area.

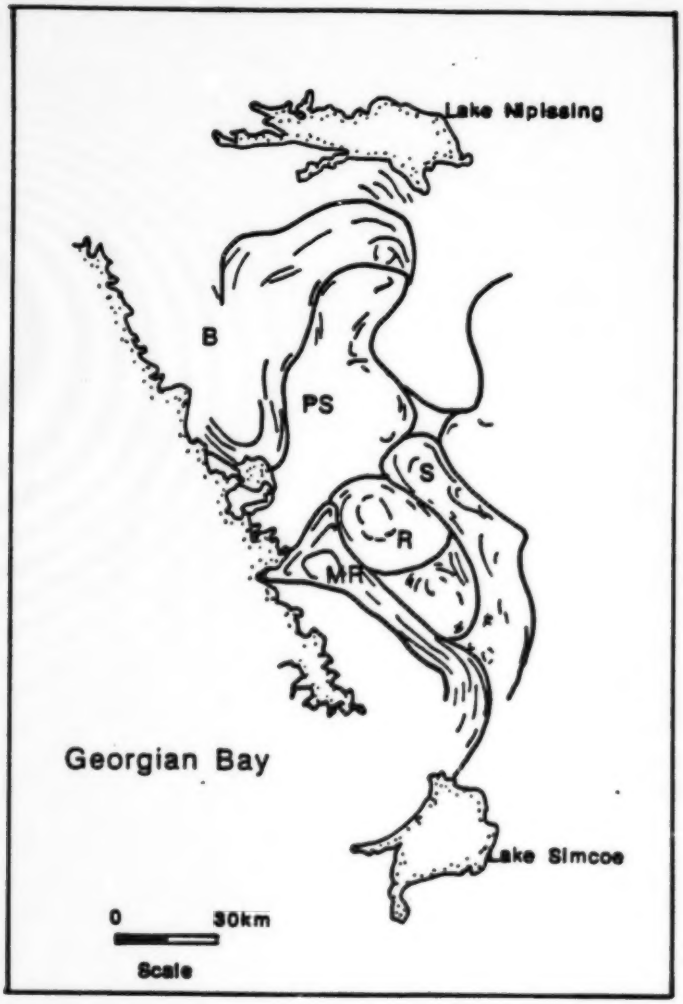


Figure 2: Tectonic domains indicated by the analysis of Harris et al. (in press). -MR: Moon River Subdomain, R: Rosseau Subdomain, S: Seguin Subdomain, PS: Parry Sound Domain, B: Britt Domain.

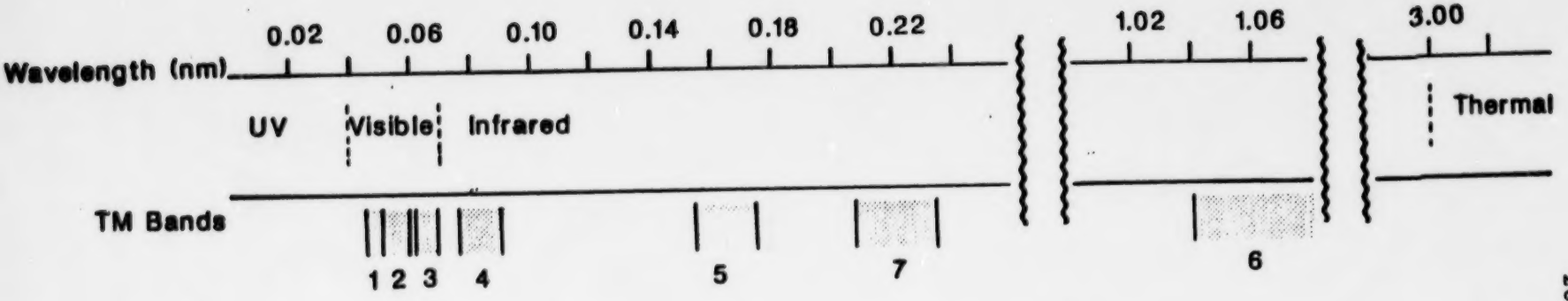


Figure 3: Thematic Mapper (TM) band location in the electromagnetic spectrum.

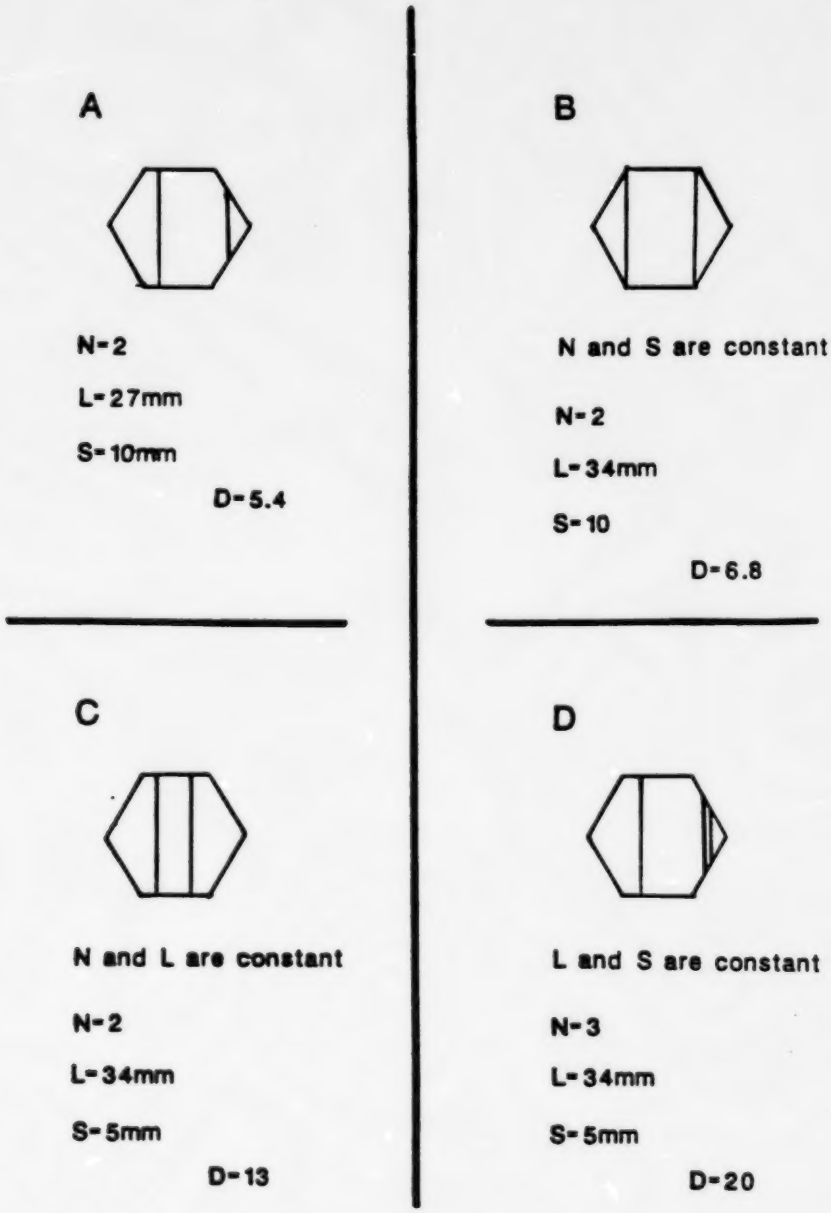
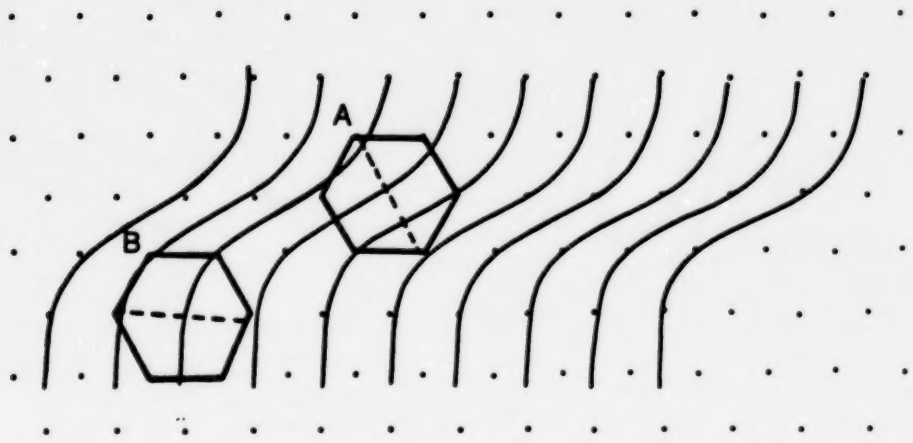


Figure 5: Comparison between various lineament patterns, L, N, and S variables and function D. Case "A" represents a low lineament density zone. In case "B", the hexagonal cell covers longer lineaments, which is reflected by the higher D value. In case C, the spacing S decreases. Finally, pattern D causes N alone to change value. Function D was the only value to record all the changes from A to D.



A

N=3
L=40mm
S=6mm

D=20

B

N=2
L=20mm
S=9mm

D=4

Figure 6: Shear zone geometry redrawn after Ramsay (1980), over which is superposed a rhombic grid. The hexagon in the unsheared portion has a lower lineament density than within the shear zone, as indicated by the parameters N, L, and S.

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